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DEVELOPMENT OF AN INTEGRATED SET OF RESEARCH FACILITIES FOR THE SUPPORT OF RESEARCH FLIGHT TEST

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Abstract

The Ames-Dryden Flight Research Facility (DFRF) serves as the site for the conduct of high-risk flight research on many one-of-a-kind test vehicles like the X-29A advanced technology demonstrator, F-16 advanced fighter technology integration (AFTI), AFTI F-111 mission adaptive wing, and F-18 high-alpha research vehicle (HARV). Ames-Dryden is on a section of the historic Muroc Range. The facility is oriented toward the testing of high-performance aircraft, as shown by its part in the development of the X-series aircraft.[1] Given the cost of research flight test and the complexity of today's systems-driven aircraft, an integrated set of ground support experimental facilities is a necessity. In support of the research flight test of highly advanced test beds, the DFRF is developing a network of facilities to expedite the acquisition and distribution of flight research data to the researcher. This network consists of an array of experimental ground-based facilities and systems as nodes and the necessary telecommunications paths to pass research data and information between these facilities. This paper presents a status of the current network, an overview of current developments, and a prospectus on future major enhancements.

Nomenclature

AFTI	advanced fighter technology integration
ARC	Ames Research Center
CIMS	calibration information management system
Code U	Flight Operations and Research Directorate of the Ames Research Center
CODN	Code U data network
CPU	central processing unit
CRT	cathode ray tube
DAF	Data Analysis Facility
DE	dynamics explorer
DFRF	Dryden Flight Research Facility
DTI	digital terminal interface
FDMSS	flight data mass storage subsystem
HARV	high-alpha research vehicle
kbs	kilobits per sec
LAN	local area network
MAGIC	master graphics interactive console
MAP	macro arithmetic processor
Mbs	megabit per sec
MCC	mission control center
megabits	millions of bits
MFLOPS	millions of floating point operations per sec
MIPS	millions of instructions per sec
megabytes	millions of bytes
NALF	Naval Auxiliary Landing Field
NASA	National Aeronautics and Space Administration
NASCOM	NASA communications system
NISDN	NASCOM integrated system digital network
PMAS	postmission analysis system
PSCN	program support communications network
PTAPS	parallel telemetry acquisition and processing system
RF	radio frequency
RIM	real-time interactive map
SME	Solar Mesospheric Explorer
SMM	Solar Maximum Mission
TCP/IP	Transmission Control Protocol/ Internet Protocol
TDMA	time division multiple access
TRAPS	telemetry/radar acquisition and processing system
WATR	Western Aeronautical Test Range

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Introduction

With the advent of testing complex systems-driven aircraft like the X-29A, the need has become apparent for a cost effective, staff efficient, technologically superior set of integrated ground-based experimental facilities to support the real time and postmission aspects of research flight test. This support is not limited to the test site at which research flight test is being conducted. The Flight Operations and Research Directorate (Code 0) of the NASA Ames Research Center (ARC), headquartered at Edwards, California, has developed and is continuing to evolve a data network to meet the full spectrum of requirements to support research flight test. The Code 0 data network (CODN) (Fig. 1) is a complex set of ground-based experimental facilities, serving as nodes, and the telecommunications paths interconnecting these nodes. The major facilities included within the network are (1) the NASA Western Aeronautical Test Range (WATR), including sites at the Ames Research Center, Dryden Flight Research Facility (DFRF), Naval Auxiliary Landing Field (NALF) at Crows Landing, and the capability of various mobile sites;[2] (2) the Dryden Data Analysis Facility (central computer complex); (3) the NASA Integrated Test Facility; (4) the NASA Flight Loads Research Facility; and (5) the Dryden calibration information management system. These facilities are interconnected by a set of data telecommunications links using copper, fiber optics, free air and extraterrestrial links using three different satellite networks.

Given the ever-increasing cost of research flight test, the increasing amount of flight test data acquired from complex systems-driven research aircraft, and the need for rapid turnaround of research data, the design challenge for a network to support this environment is complex (Fig. 2). As the amount of flight research data acquired onboard a research vehicle increases, the need for the researcher to look at more information and less raw data also increases. To support programmatic milestones and day-to-day research flight operations, the time required for the researcher t access the research information must decrease. The CODN has been, and is being, evolved to satisfy these inverse relationships. Although not covered directly, the reader must be aware of the necessary configuration control-management processes that accompany this approach to network development. This paper presents the current status of the CODN and a prospectus of the developments now underway or in the planning stage.

Real-Time Mission Support

The physical front-end of the CODN is in the NASA WATR. This facility is responsible for the real-time acquisition, processing, display and distribution of flight test data during a research mission.[3] Multiple telemetry tracking systems, in manual, autotrack or radar slave mode, acquire data in real time from research vehicles. These systems and their associated radio frequency (RF) subsystems deliver the flight test data streams to the real-time processing systems in the WATR mission control centers (MCC).

The current configuration allows for two simultaneous downlink streams from each research vehicle. The downlink streams are limited to 1 megabit per sec (Mbs) per stream. The downlink bit stream is time tagged, compressed, converted to engineering units, limit checked, and placed in a current values table at a maximum rate of 200,000 words per sec per stream. Information in the current values table is then available to the real-time processing system for engineering computations which are also placed in the current values table. The current values table is currently configured for 4096 calibrated parameters and 3200 parameters derived from the calibrated parameters. This composite of calibrated downlink data and computed data will be delivered to the MCC via a fiber optic-based local area network[4] (LAN) in the Ethernet Transmission Control Protocol/Internet Protocol (TCP/IP). Unander and Sheldon[4] point out many of the design considerations necessary for a subsystem with the necessary performance requirements to meet real-time mission control and monitoring. Numerous display devices in the MCC get required parameters for display in real time from the LAN. The current LAN operates at 400 megahertz. A new LAN is under development that will operate at 1.7 gigahertz. Figure 3 depicts this process and some typical types of displays available in the MCC.

The computational engine used for real-time processing consists of a cluster of three Gould minicomputers (Gould Electronics, Inc., Cleveland, Ohio), two 32/6780s and a 32/9780, in a shared memory configuration augmented by a macro arithmetic processor (MAP) 300 array processor (CSP Inc., Billerica, Massachusetts). This configuration is called the telemetry-radar acquisition and processing system (TRAPS) and is designed for fixed-base operations. Figure 4 depicts the current TRAPS concept that is in the evolutionary design and implementation process. Figure 5 shows the TRAPS and its interface to the real-time display subsystem in the mission control centers. Figure 6 shows a detailed view of the TRAPS and its associated peripherals and interfaces.

For mobile operations, the computational engines are Motorola, Inc. (Phoenix, Arizona) 68020 based microprocessors, configured in a board level distributed processing architecture, called the parallel telemetry acquisition and processing system (PTAPS). Figure 7 depicts a modular representation of the PTAPS and its corresponding interfaces and peripherals. Mobile operations capability plays a vital part in research flight test at the ARC. Projects requiring special operations environments use this capability. The WATR mobile configuration allows for rapid prototyping of new ground-based monitoring and test evaluation techniques. Due to its relatively small size and ease of configuration control, these new techniques can be realized in a short time and refined for subsequent implementation in a more formal fixed-base environment. Figure 8 shows the current PTAPS hardware configuration for mobile operations. The PTAPS is being installed in a new mobile configuration[5] (Fig. 9). The configuration and capability of this implementation has been based on an assessment of NASA's requirements for aeronautics, sounding rockets, balloons, and low earth orbiters.

This configuration was used for aeronautics support in April 1988. It will be used for low earth orbiter support in September 1988, using a mobile 20-ft antenna to ensure the necessary link margins for the radiated signal from spacecraft like the Dynamics Explorer (DE), Solar Maximum Mission (SMM), and Solar Mesospheric Explorer (SME).

Mission Control Center

The mission control center (MCC) is where the results of the real time computational and display process come together (Fig. 10). Whether fixed or mobile, the MCC must give the researcher an interactive environment in which to conduct flight research. Given the large amounts of data telemetered from today's research vehicle, the display of research information for real-time decisions must be in a form compatible with the real-time decision process.[6] Displays must coalesce the large amounts of raw telemetered data and the resultant engineering values computed from the raw data into an easily recognizable, readable form.

Figure 11 shows sample displays for space position data. The displays are generated on a Silicon Graphics, Inc. (Mountain View, California) IRIS system using a software package known as real-time interactive map[7] (RIM). Based on the results reported by Comperini and Hammons, the addition of real-time three-dimensional displays in the mission control center has increased data usability and the safety factors necessary for research flight test. RIM takes information from the TRAPS or PTAPS via Ethernet and displays the relative position of the test vehicle with respect to the ground. The user has the capability to view the test article from the ground, from an overhead view or from a chase plane. RIM contains many display options that the user may invoke with a mouse and keyboard in the MCC. Options include the insertion of a three-instrument control panel in the lower left-hand corner of the display, an option to compute heading and elapsed time to a selected point on the ground, the removal of detail features from the map, the insertion of concentric circles around the location of the test vehicle for instant range determinations, the selection of the size of a wire frame model of the test vehicle, the activation-deactivation of specific test areas within the test range, and the prediction of mission specific flightpath information from the tracking radars and downlink telemetered data. The user can get a color hardcopy of any combination of these options by pressing a button. The hardcopy can be either paper or transparency.

Downlink and computed research engineering data is displayed via numerous devices in the MCC. Alphanumeric displays are available for either discrete parameter display or scrolling parameter display or both on the same cathode ray tube (CRT). Time history and cross plots are available via a software package known as the master graphics interactive console (MAGIC).[8] Malone and Moore have reported the real-time flexibility necessary in today's modern mission control center. MAGIC allows the researcher to monitor and alter real-time displays based on the results observed during the conduct of a research mission. The software package receives data from the TRAPS via the WATR LAN and displays it in the mission control center. The real-time program is controlled by a keyboard and mouse on a Silicon Graphics IRIS system. Figure 12 depicts a brief selection of the displays possible from the MAGIC system. Like the RIM software package, the user may get a color hardcopy of the display on the screen by a single keystroke.

After completion of the research mission, the information that was downlinked from the test vehicle is transmitted to the postmission analysis system. The flight test data-information is collected in real time for this transmission. Currently the data is transferred via magnetic media and is usually ready for analysis at the beginning of the next business day. A new interface is under development for this transmission via a network that will allow for the data to be ready before the researchers can return to their normal work stations, approximately 10 minutes. Data will be transferred to a flight data mass storage subsystem (FDMSS) (Fig. 13) at 100 Mbs. The FDMSS will have the capacity to hold >160 hr of flight data on-line for the researcher. This capacity estimate is based on a 1 Mbs downlink rate from each of the research vehicles. Flight research data is accessed upon user request from the FDMSS. In processing the request, the data is limit checked and converted to engineering units. The research flight data is now ready for postmission processing and analysis.

Postmission Analysis System

The postmission analysis system (PMAS) (Fig. 14) is centered in the Data Analysis Facility (DAF) at DFRF. The PMAS has two primary computational subsystems, the calibration information management system (CIMS) and the ELXSI 6400 central processing system (ELXSI, Triology, Ltd., San Jose, California). The CIMS is a VAX 780 hosted system (Digital Equipment Corp., Maynard, Massachusetts) used to maintain, for archival as well as operational purposes, all of the data system acquisition formats and parameter calibrations for all research vehicles at DFRF. Raw calibrated information is entered into the CIMS. It supplies the necessary calibration information for both real time and postmission processing. The information resident in CIMS is stored in and retrieved from a relational data base. The data base allows for the storage and access of all facets of calibration information. Self-checking menu type inputs relieve many of the error prone functions of calibration handling. The CIMS is a node on a fiber optic ring to all ground-based experimental facilities that will be discussed further.

The ELXSI central processing system is the heart of the postmission processing and analysis function at DFRF. The ELXSI is configured with four central processors and 48 megabytes of memory. Researchers are connected to the ELXSI by either a low speed, 19.2 kbs LAN or by an intermediate speed, 1 Mbs LAN. These local area networks will be discussed further. The ELXSI is used for detailed engineering analysis of the research flight data. Its benchmark speed of 10 Whetstone millions of instructions per sec (MIPS) per central processing unit (CPU) makes it an ideal computational engine for analysis of large numerical, structural, and aerodynamic prob-

lems. The ELXSI allows for 55 simultaneous users accessing via the low-speed LAN. The low-speed LAN is primarily used for the interactive analysis of research flight data bases. The intermediate speed LAN is a bus architecture and allows for numerous simultaneous users. The intermediate speed LAN is used to transfer bulk data from research flight data bases to advanced graphics workstations. Current research flight data bases are largely sequential in structure. A study has been completed on the advantages of evolving to a relational data base management structure for flight data.[9] Based on Smith's findings, work on a relational data base management system for flight data handling will begin in the summer of 1988. As was pointed out by Phillips, every data point needs to be available to the researcher to be "worked-up."[10] The relational data base approach provides the researcher with a user friendly method to reference and cross-reference each data point.

The calibration management information system supplies the DFRF with a complete system of software, hardware, and procedures for handling the calibration and instrumentation information required for research flight test. Calibration information consists of that which is unique to a particular instrument as well as its implementation on any given research vehicle. CIMS tracks, archives, and allows for the maintenance of this information. The process and data flow for the CIMS is depicted in Fig. 15.

Data Telecommunications System

The data telecommunications system of the CODN (Fig. 16) is the backbone of the network by which the nodes within the network communicate with each other. As was stated earlier, there are two primary local area networks that interlink the ground-based experimental facilities at Dryden. In addition to the local area networks, DFRF has access to three separate extraterrestrial networks.

The program support communications network (PSCN) is a NASA-wide satellite network used for administrative data transmission. DFRF serves as a West Coast gateway for the PSCN. Trunk lines from the Jet Propulsion Laboratory in Pasadena, California, Vandenburg Air Force Base, and other tail circuits to NASA contractors in southern California terminate at DFRF for transmission to the satellite. The PSCN supports telephone and teletype communications, video teleconferencing, and bulk data transfer between PSCN nodes.

The NASCOM integrated system digital network (NISDN) is a time division multiple access (TDMA) satellite network used for real-time mission support. The CODN has three fixed nodes for the NISDN at Ames-Moffett, Ames-Dryden, and at NALF Crows Landing. The WATR is in the process of adding a mobile NISDN earth station to its mobile configuration. This network is used for real-time mission support of both the aeronautics and space program.

A NASA communications (NASCOM) earth station also exists at Dryden for the exclusive support of National Space Transportation System missions. This network is used heavily during simulations, launch, on-orbit, and landing support of Space Shuttle missions. Data from the orbiter is acquired with WATR telemetry and radar tracking systems and linked to the Kennedy Space Center (KSC) and the Johnson Space Center (JSC) in real time or in postmission playback mode. The information linked to JSC and KSC can be either real-time data from the shuttle orbiter, configured by the relational data base information contained in the CIMS, or space position information relative to a particular mission's flight profile.

As already stated intrasite data at DFRF is telecommunicated by the two local area networks. The low-speed LAN is hosted on a ROLM digital voice-data switch (Rolm Corp., Santa Clara, California). The switch currently supports 300 user data ports. Users can interface to the switch either by a dedicated digital terminal interface (DTI) or by conventional modem on a standard telephone line, allowing for access to the system from remote locations. Outside access has necessitated the addition of security procedures, hardware, and software to prevent unauthorized access.

The intermediate speed LAN is currently in a development phase. Three initial lines of a ring concept have been installed between the CIMS and the WATR, CIMS and the ELXSI processing system; the ELXSI processing system and the simulation facility (future ITF); and the ELXSI processing system and user graphics workstations. This LAN uses fiber optic lines and Ethernet TCP/IP. Future plans include a ring for facility bulk data transfer for direct mission support and a ring for researcher analysis data transfer. This portion of the CODN will evolve based on user requirements and resource availability.

Concluding Remarks

The CODN is a concept that will continue to grow and evolve as research flight test requirements change. Yardley pointed out the advantage of using evolutionary development to sustain a growing operational capability.[11] The CODN hardware and software will be perfected over a substantial period by operating and modifying it. The cost of research flight test dictates that the maximum amount of data per flight hour be delivered to the researcher in the minimum amount of time. A reliable, fast, and effective network is a necessity in today's research flight test environment. Although the network will grow, it will grow in a controlled environment. Configuration control and management of a network for handling this type of information is a necessity to meet the goals of reliability and effectiveness.[12] Yergensen and Rhea have reported the necessary processes and potential pitfalls. The capability to take a network node to the test site is also an emerging necessity for research flight test. These factors and considerations have been, and will continue to be, emphasized in the development and evolution of the CODN.

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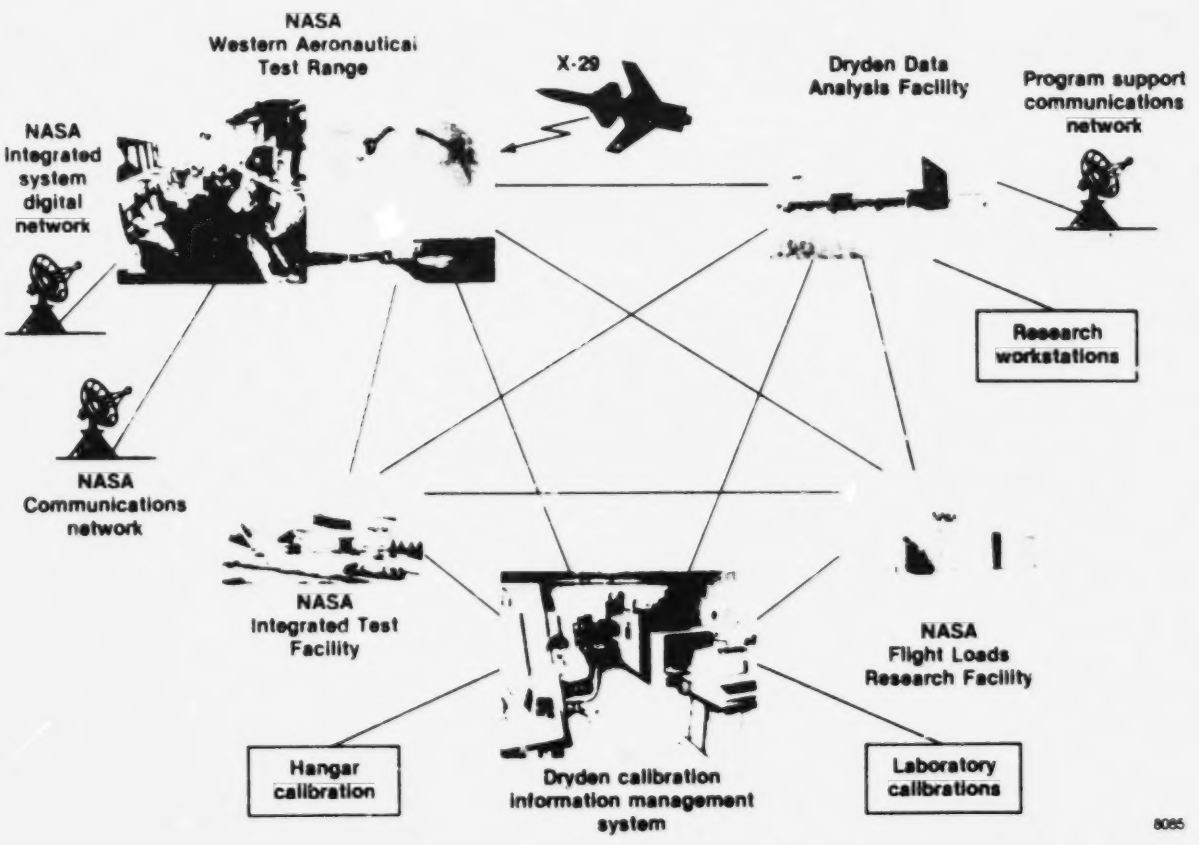

Fig. 1 Code 0 data network, Ames Research Center.

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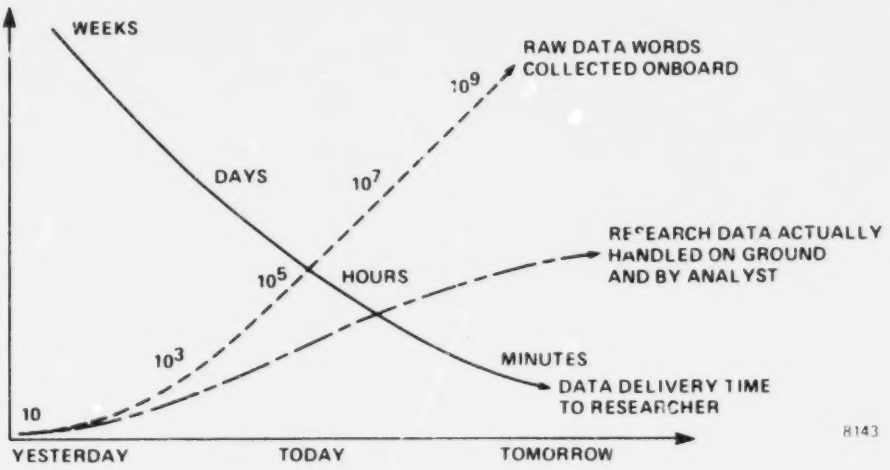
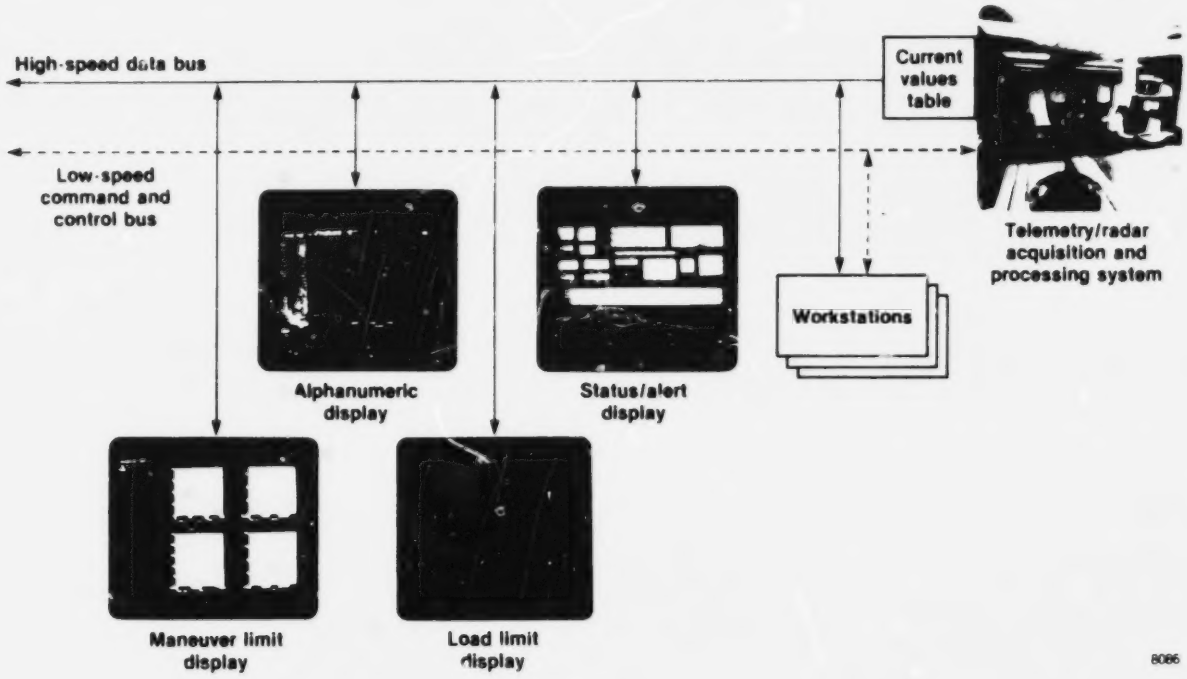


Fig. 2 Code O design challenge, Ames Research Center.



(a) Displays.

Fig. 3 Real-time data to mission control center displays, Ames Research Center, Western Aeronautical Test Range.

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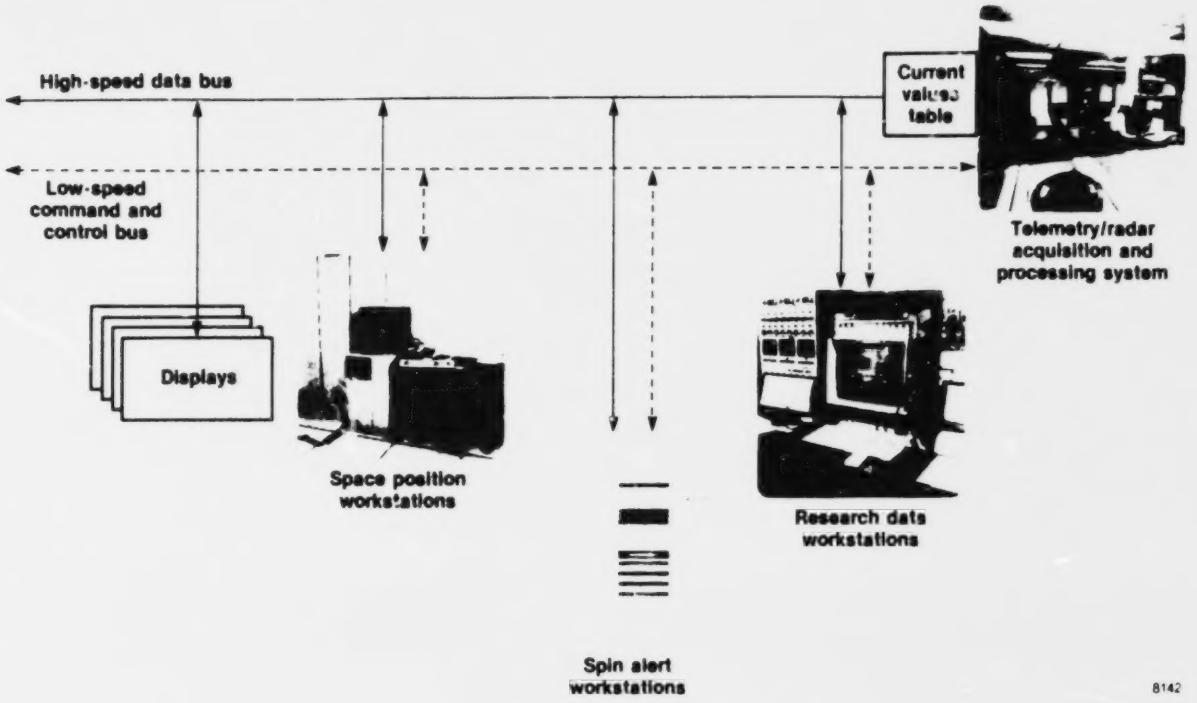

(b) Workstations.

Fig. 3 Concluded.

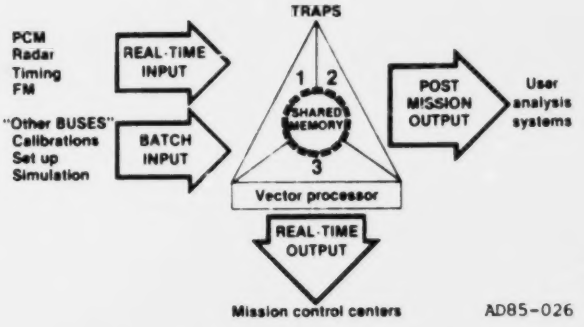

Fig. 4 Telemetry-radar acquisition and processing system, Western Aeronautical Test Range.

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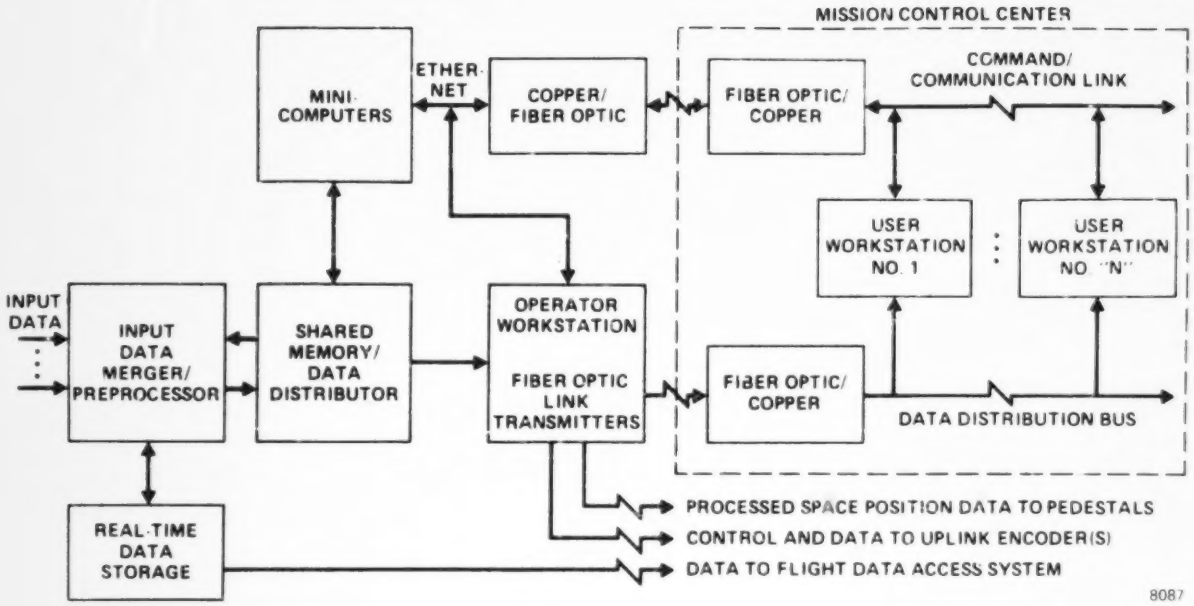


Fig. 5 Real-time processing and display system, Western Aeronautical Test Range.

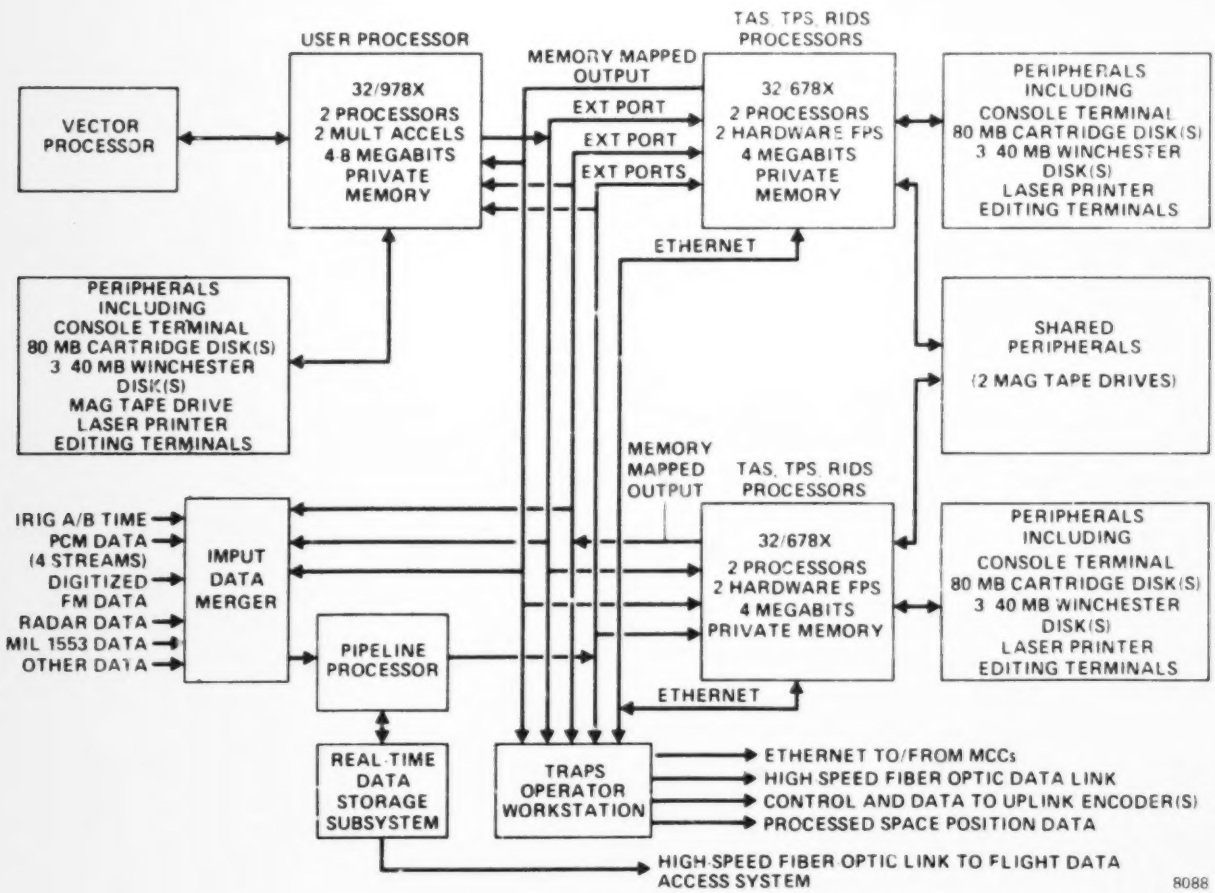


Fig. 6 Telemetry-radar acquisition and processing system (TRAPS).

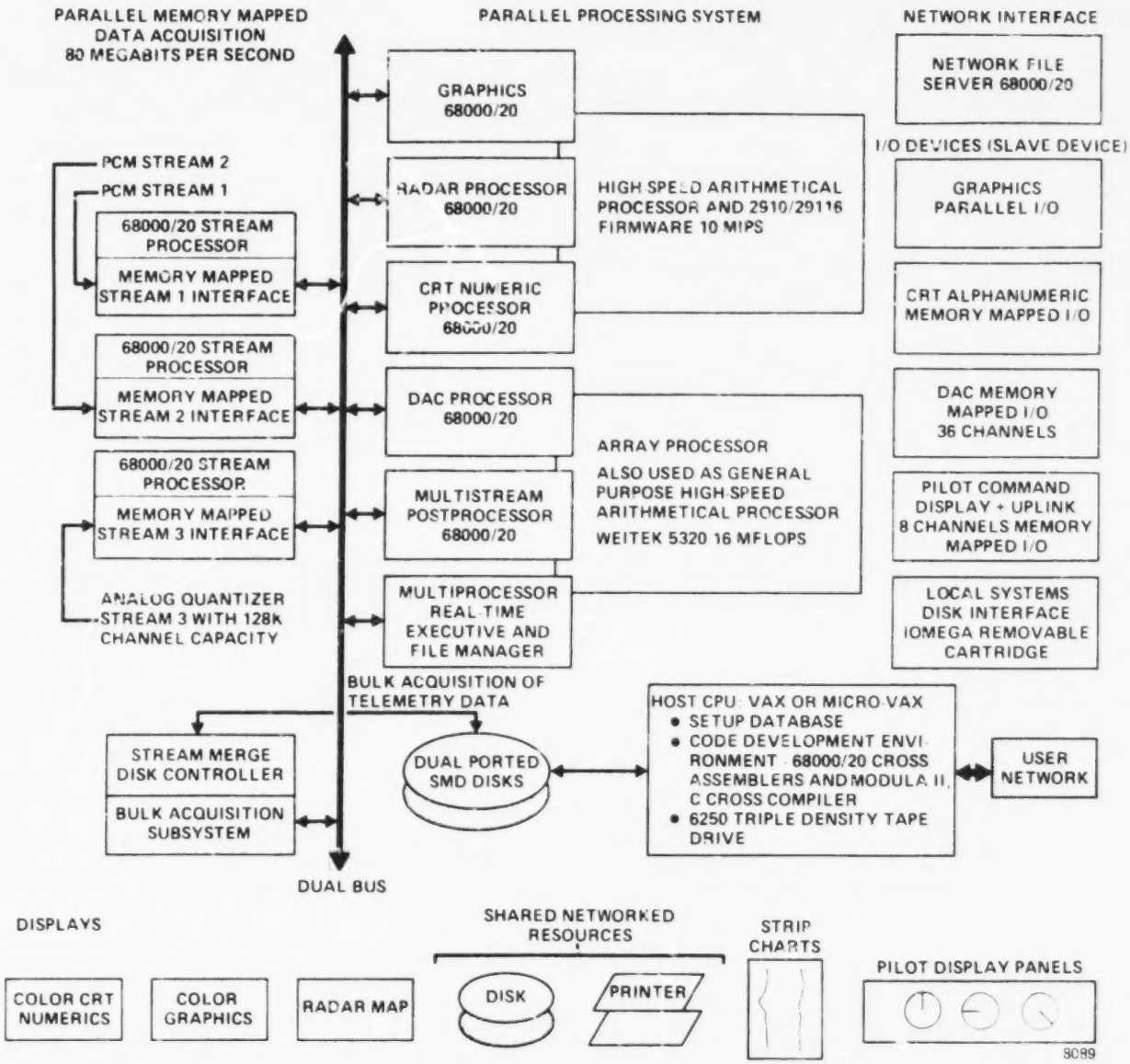


Fig. 7 Parallel telemetry and processing system, Western Aeronautical Test Range.

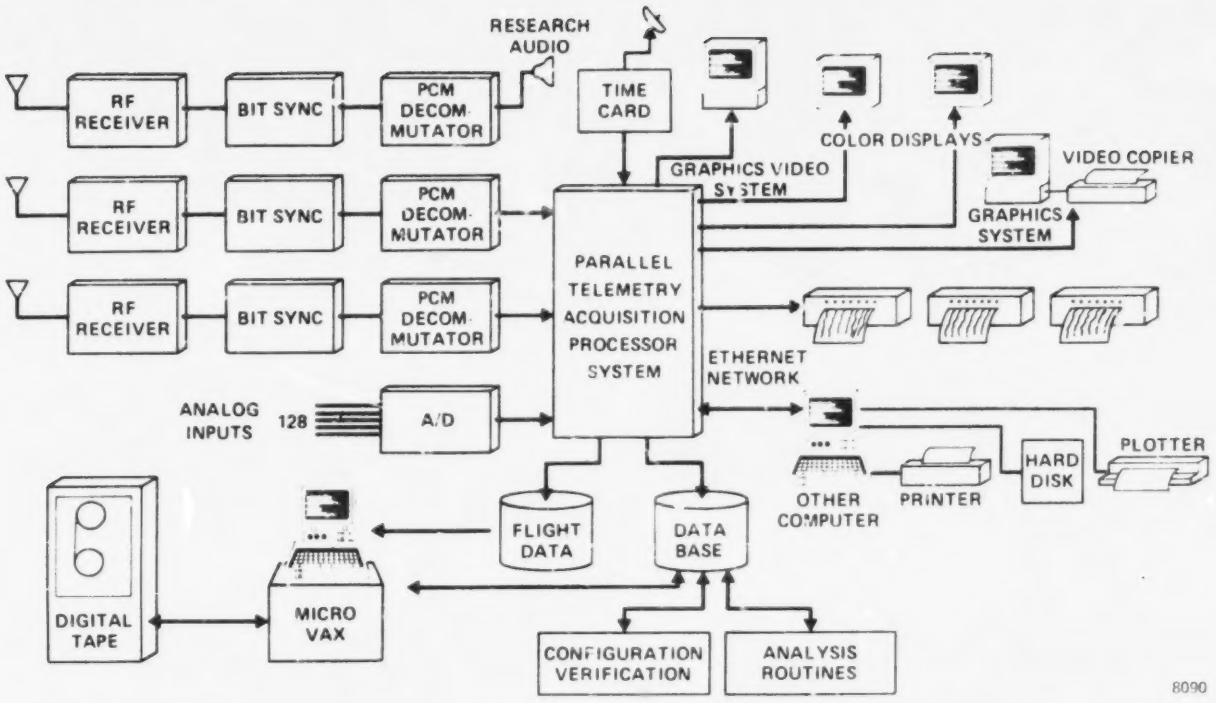
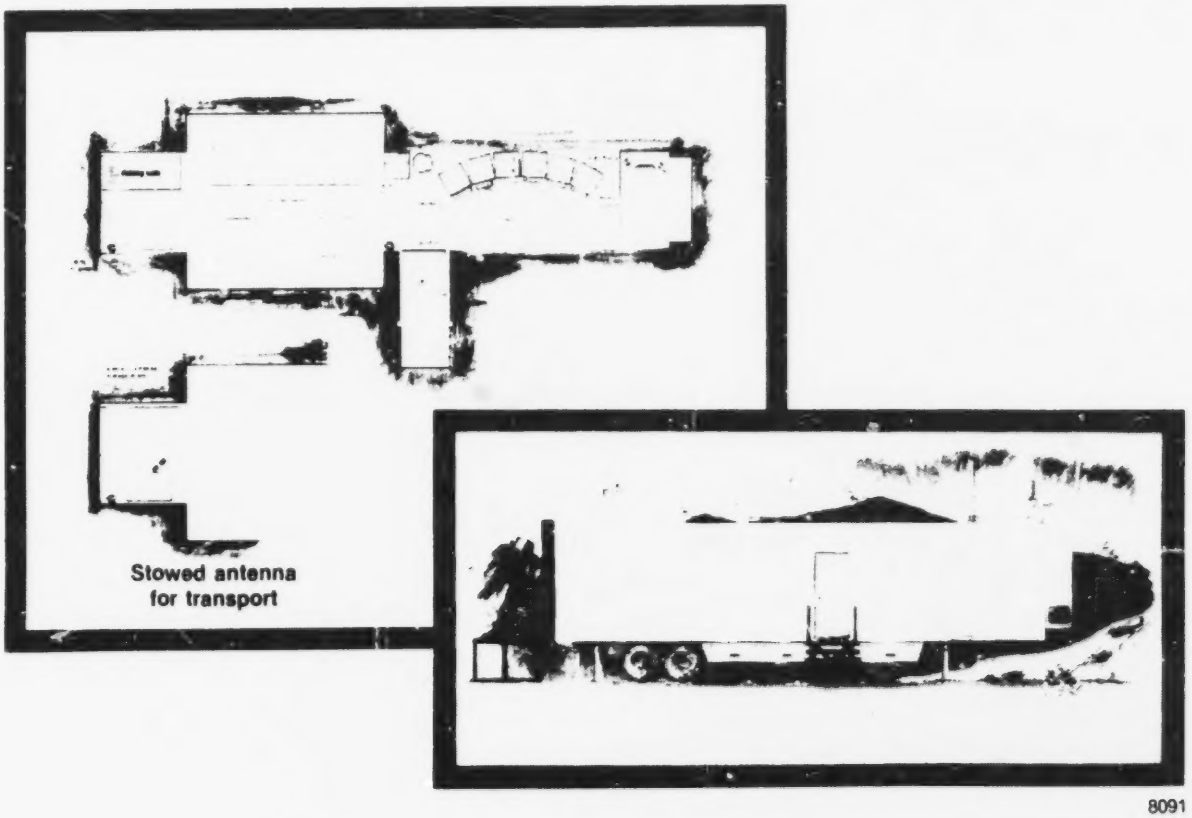


Fig. 8 Current parallel telemetry and processing system (PTAPS) configuration for mobile operation.



Figs. 9 Mobile configuration, Western Aeronautical Test Range.

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Fig. 10 Blue room, mission control center, Western Aeronautical Test Range.

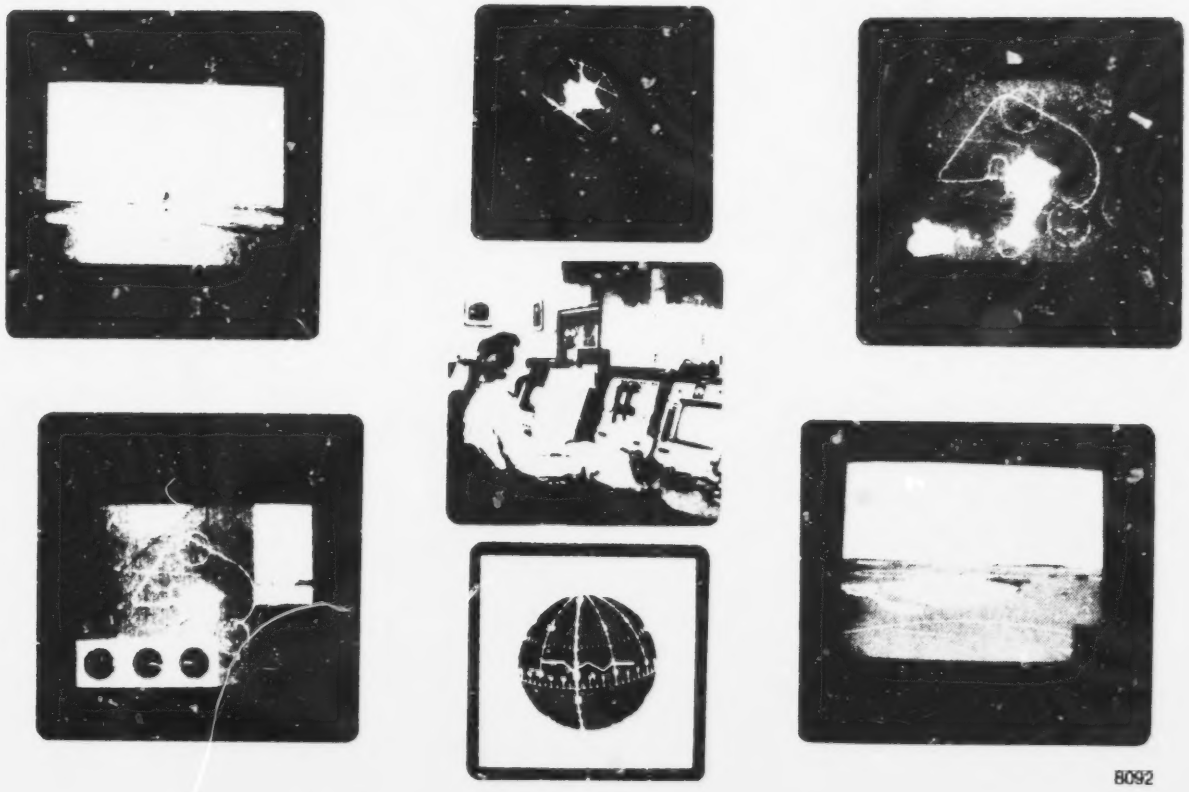

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Fig. 11 Real-time interactive map displays.

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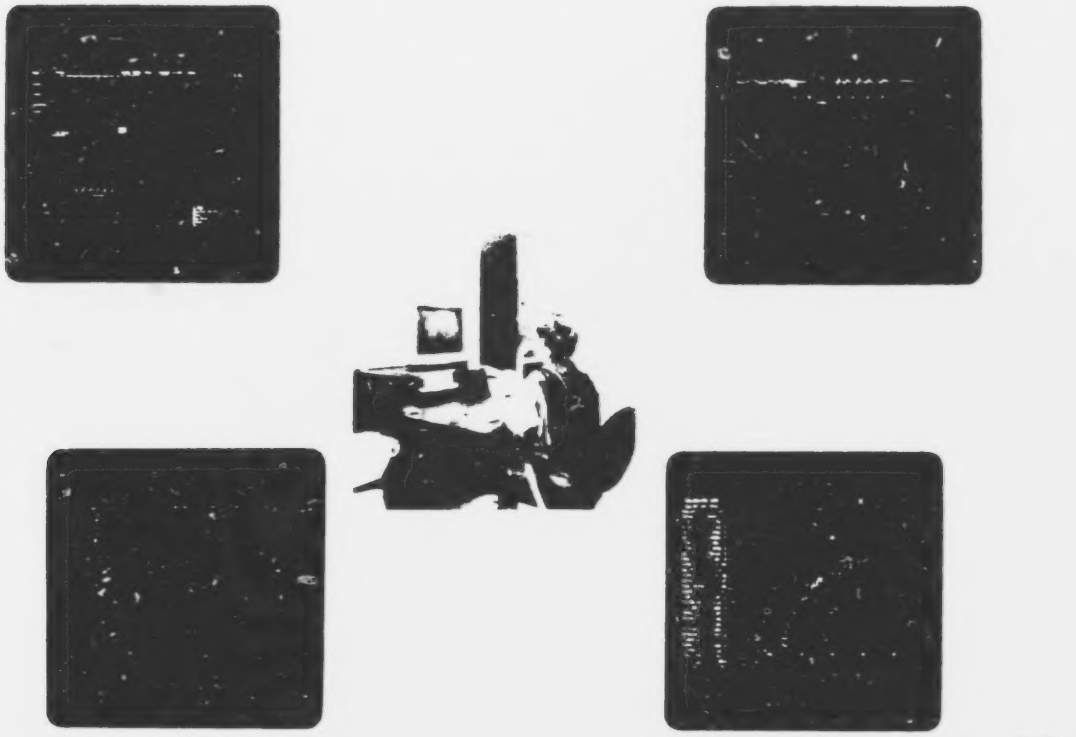

Fig. 12 Master graphics interactive console (MAGIC) displays.

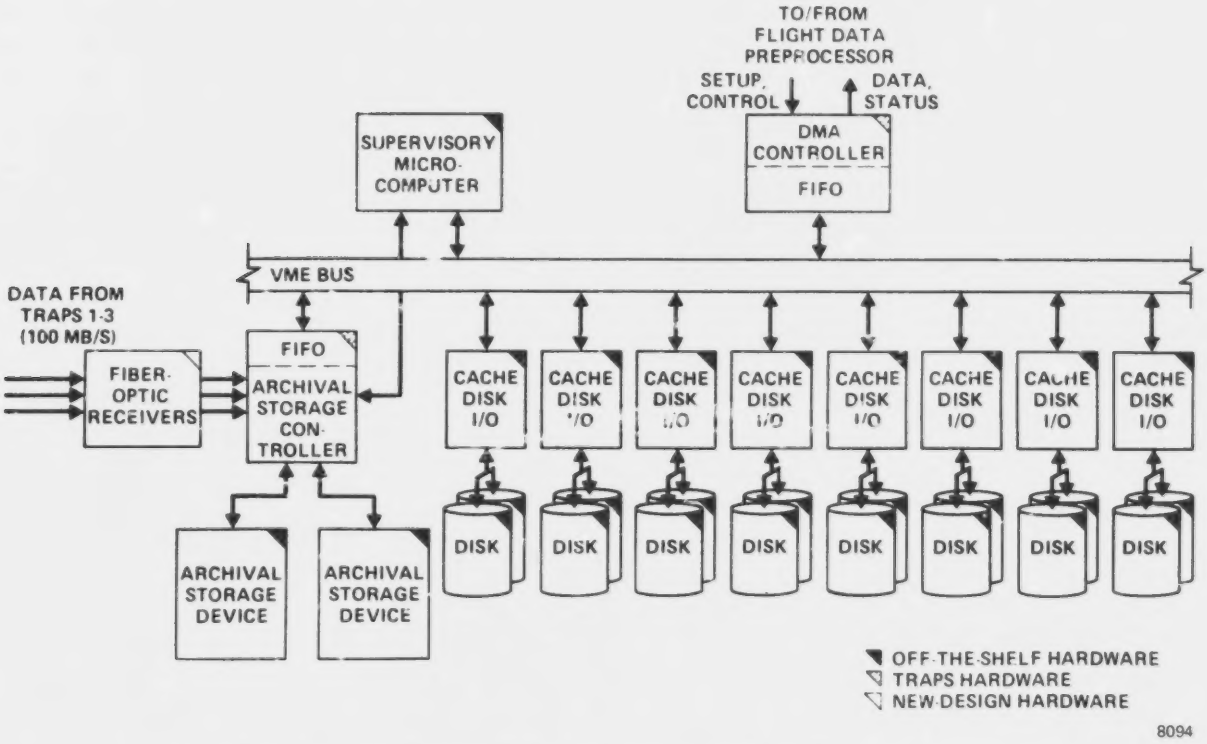

Fig. 13 Flight data mass storage subsystem, Code O data network, Ames Research Center.

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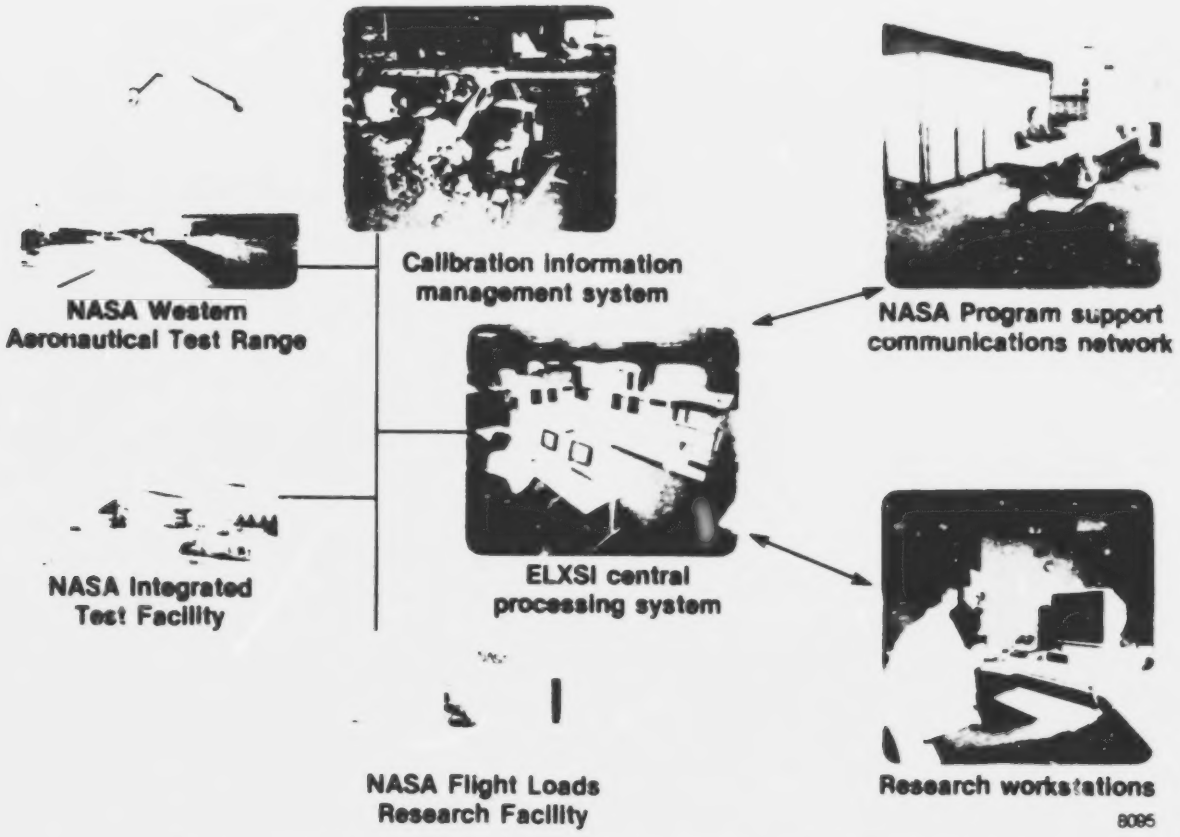

Fig. 14 Postmission analysis system, Code O network, Ames Research Center.

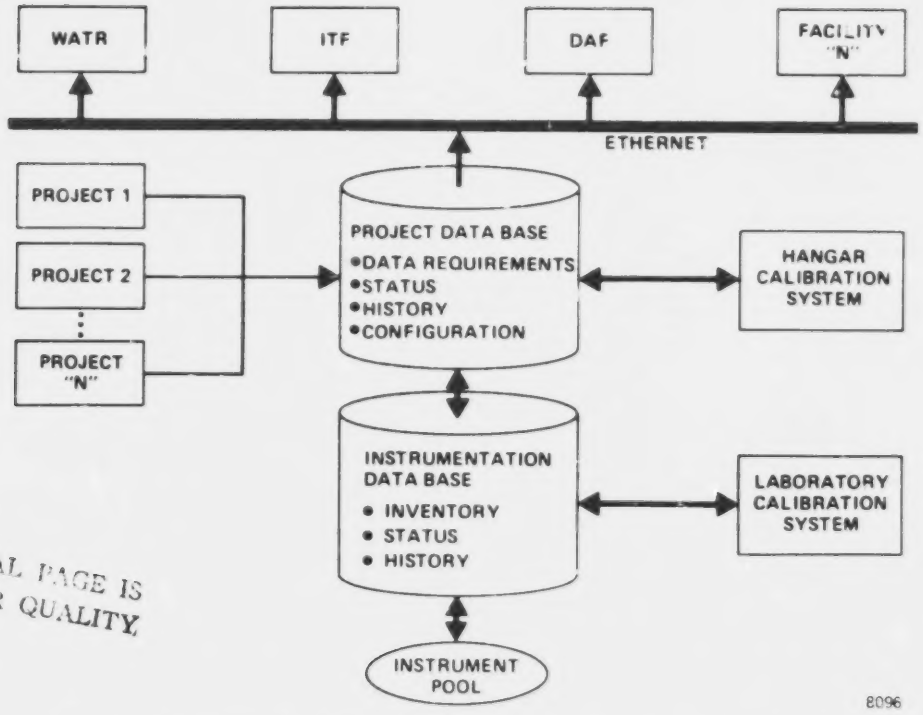

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Fig. 15 Calibration information management system, Ames Research Center.

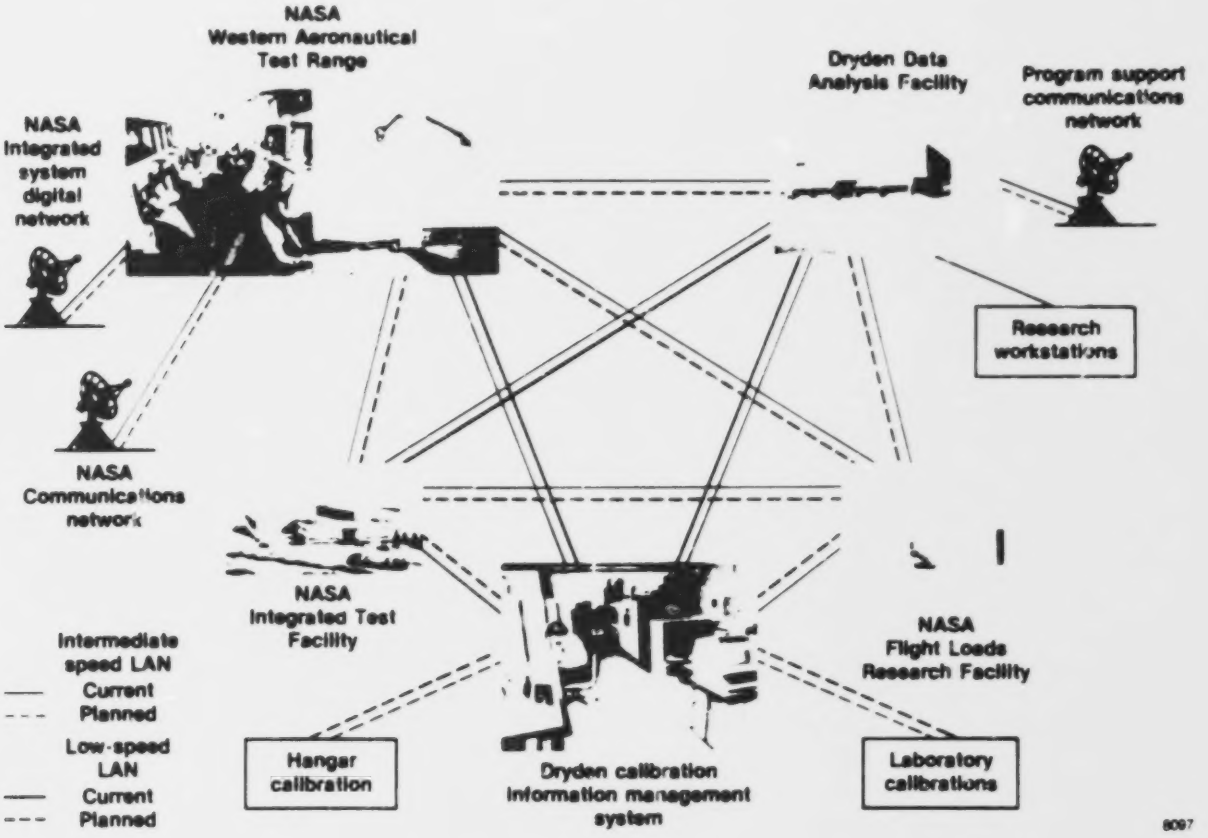

Fig. 18 Data telecommunications system, Code O data network, Ames Research Center.

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16. Abstract

The Ames-Dryden Flight Research Facility (DFRF) serves as the site for the conduct of high-risk flight research on many one-of-a-kind test vehicles like the X-29A advanced technology demonstrator, F-16 advanced fighter technology integration (AFTI), AFTI F-111 mission adaptive wing, and F-18 high-alpha research vehicle (HARV). Ames-Dryden is on a section of the historic Muroc Range. The facility is oriented toward the testing of high-performance aircraft, as shown by its part in the development of the X-series aircraft. Given the cost of research flight test and the complexity of today's systems-driven aircraft, an integrated set of ground support experimental facilities is a necessity. In support of the research flight test of highly advanced test beds, the DFRF is developing a network of facilities to expedite the acquisition and distribution of flight research data to the researcher. This network consists of an array of experimental ground-based facilities and systems as nodes and the necessary telecommunications paths to pass research data and information between these facilities. This paper presents a status of the current network, an overview of current developments, and a prospectus on future major enhancements.

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